



Industry 4.0

A Discussion of Qualifications and
Skills in the Factory of the Future:
A German and American Perspective

April 2015



Project Summary

In April 2014, VDI The Association of German Engineers and ASME American Society of Mechanical Engineers joined efforts to study the impact of industrial innovation on the role of humans in the future of manufacturing. A team of ten early career engineers from diverse sectors of industry and academia worked for eight months to research the development needs of the workforce in the factory of the future, to identify the current challenges, and to recommend initiatives to prepare the future workforce for changes in their work environment. The ongoing initiatives of the Advanced Manufacturing Program and Industry 4.0 led by the United States and Germany respectively were reviewed to identify areas for joint collaborative efforts and prepare industry for the technology and workforce demands of the factory of the future.

The manufacturing sector is very important for future economic growth in manufacturing-based economies such as the USA and Germany. Industrial history has shown that the progression of manufacturing has grown in revolutions versus steady changes. Current technological improvements are converging towards the possibility of another one of these aforementioned revolutions. In an effort to strengthen and increase

their respective economies and manufacturing sectors, the USA and Germany have funded initiatives to spur on this revolution. The USA refers to their program as the Advanced Manufacturing Program and Germany refers to theirs as Industry 4.0. With these ideas in mind, a small coalition of German and American early career engineers collaborated to contribute to the discussion on what could be done to supplement these movements. While the programs address the further development of critical technologies to revolutionize the manufacturing industry, the creation of a workforce that can be effective in the environments created by those revolutions remain mostly unaddressed. Discussion and exploration of skilled labor forces interacting with new technologies and the resulting aspects of these technologies were used to derive an understanding of the necessary qualifications and skills that will be needed by future skilled labor forces. This future factory environment and personnel roles imagined in this discussion were then subsequently used to compile a list of recommendations and ideas of how organizations such as VDI and ASME can positively contribute to the advanced manufacturing movement.

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Authors



Gehrke, Lars, Ph.D. Candidate at Volkswagen Group & Chair of Enterprise Logistics, TU Dortmund



Kühn, Arno T., Research Fellow & Team Leader, Fraunhofer IPT



Rule, David, Process Engineer, Alstom Power Thermal Services



Moore, Paul, Post-Doc, University of Florida



Bellmann, Christoph, Graduate Student & Research Assistant, University of Bremen, Fraunhofer IFAM



Siemes, Sebastian, Process Development Engineer, Rosenberger Hochfrequenztechnik GmbH & Co. KG



Dawood, Dania, Graduate Student & Working Student, University of Hamburg, Siemens Wind Power



Singh, Lakshmi, Project Development Manager, Dresser-Rand Group



Kulik, Julie, Mechanical engineer, DCMA Boeing



Standley, Matthew, Project Manager, Westinghouse Electric Company

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1 Introduction

The manufacturing industry continues to be a central driver of growth for economies worldwide. It makes tremendous contributions to trade, research and development, and productivity, generating 70% of exports and 90% of research and development investment in major manufacturing economies. Global consumption of goods is expected to double to \$64 trillion in the next 15 years, driving the demand for manufactured goods and services. Per IHS global insight, the sector is estimated to grow at 2.5% in developed economies and by 7.5% in developing economies [Manyika et al., 2012].

The impact of manufacturing growth on a country's economy over time is significant. Historically, we have seen that as economies advance and become wealthier, the manufacturing share of the gross domestic product peaks, beyond which the consumption shifts towards services resulting in a decline in manufacturing jobs. In advanced and developed economies, the significance of manufacturing shifts more towards innovation driving productivity, efficiency, and sustainability. This shift has led to a global manufacturing environment with developing economies providing the source of new customers and low-cost production [World Economic Forum, 2012].

As global competitiveness and demand for increased performance increases, developed economies invest in technologies and process improvements to drive productivity. The continued adoption of advanced manufacturing technologies into industrial processes and products leads to a factory of the future that is envisioned to be highly innovative, networked, and flexible. Innovative technologies, such as advanced robotics, additive manufacturing, and digital manufacturing, are increasing the significance of information management and intelligent platforms leading to the utilization of big data and the internet of things. The high tech manufacturing environment will need skilled production labor with expertise to work with new materials, machines, and especially information [Siemens AG, 2013].

The demand for technical talent will drive the shift of job creation within the manufacturing industry requiring more qualified personnel on the shop floor. Companies will need a skilled workforce to develop and run advanced manufacturing tools and systems and to analyze the data received from machines, consumers, and global resources. This results in a rising need for skilled workers trained in cross-functional areas and with capabilities to manage new processes and information systems.

As the skills and qualifications of the workforce become the key to success of a highly innovative factory, the role of the human factor in the advanced manufacturing of the future is of increased significance. In order to develop the potential talent pool, governments, universities, and industry have partnered to collaborate efforts in workforce training and development.

There is great interest in strengthening the manufacturing Industries in both the United States and Germany. However, the approaches of the two countries differ slightly in direction and scope. In the United States, business driven profitability goals are key drivers of outsourcing to low cost manufacturing countries. Thus, initiatives in the United States are focused on bringing the production back into the country whereas in Germany the main focus is on keeping the production in the country [Bauernhansl et al., 2014], [Nikolaus, 2014]. Demographic aging in Germany is a significant concern for manufacturing companies, hence, Industry 4.0, led by the German government, is a strategy towards improved competitiveness.

In April 2014, the ASME American Society of Mechanical Engineers and VDI The Association of German Engineers (VDI) joined efforts to study the impact of industrial innovation on the role of humans in the future of manufacturing. A team of ten early career engineers from diverse sectors of industry, government, and academia worked for eight months to research the development needs of the workforce in the factory of the future, to identify the current challenges, and to recommend initiatives to prepare the future workforce for changes in their work environment. The ongoing initiatives of the Advanced Manufacturing Program and Industry 4.0 led by the United States and Germany respectively were reviewed to identify areas for joint collaborative efforts and prepare industry for the technology and workforce demands of the factory of the future.

The remainder of the paper is structured as follows.

- **Chapter 2** provides the historical impact of manufacturing in the USA and Germany and the current initiatives led by both countries on advanced manufacturing technologies.
- **Chapter 3** describes the situation in a factory of the future with respect to the human factor. Based on identified impact areas, the recommended future qualifications and skills of the skilled labour are derived.

■ **Chapter 4** compares the current initiatives launched by USA and Germany for workforce training and development.

■ **Chapter 5** develops strategies on addressing the challenges of tomorrow and provides recommendations to industry, government, academia and professional societies such as VDI and ASME.

2 Manufacturing Innovation - Past and Present

In the past two hundred and fifty years since the dawn of the Industrial Revolution, the world has undergone a tremendous transformation. People now live longer, healthier, more productive, and more fulfilling lives. All the while, manufacturing has been one of the key drivers in advancing technology, changing society, and shaping the world around us. The introduction of the assembly line by Henry Ford in 1913 constitutes a great example of the incredible influence manufacturing has on society [Womack et al., 2008]. Today, we are on the brink of the fourth industrial revolution that is expected to significantly change Industries again. In order to bring this new revolution in line with the historical development of Industries, the four industrial revolutions are described in chronological order in the following. Figure 1 portrays the four stages of the Industrial Revolution and sets representative examples of each.

The First Industrial Revolution

The First Industrial Revolution, in the late 18th and early 19th centuries, started with the mechanization of manufacturing. The fundamental change that spurred the industrialization was the shift in power sources. The steam engine powered by coal, for example, was able to output mechanical energy keeping factories producing faster and more efficient. With this mechanization, manual handwork was replaced and the workers were operating the first machine tools [Stearns, 2012]. This fundamental shift led to a change of the required skills and knowledge needed by the new working class. With the increasing number of people working together, the specialization of skills emerged [Stearns, 2012]. The higher productivity from the increased use of steam power and machine tools led to sustained economic growth and opportunities for employment, thus influencing social and cultural aspects of life in Germany and the USA.

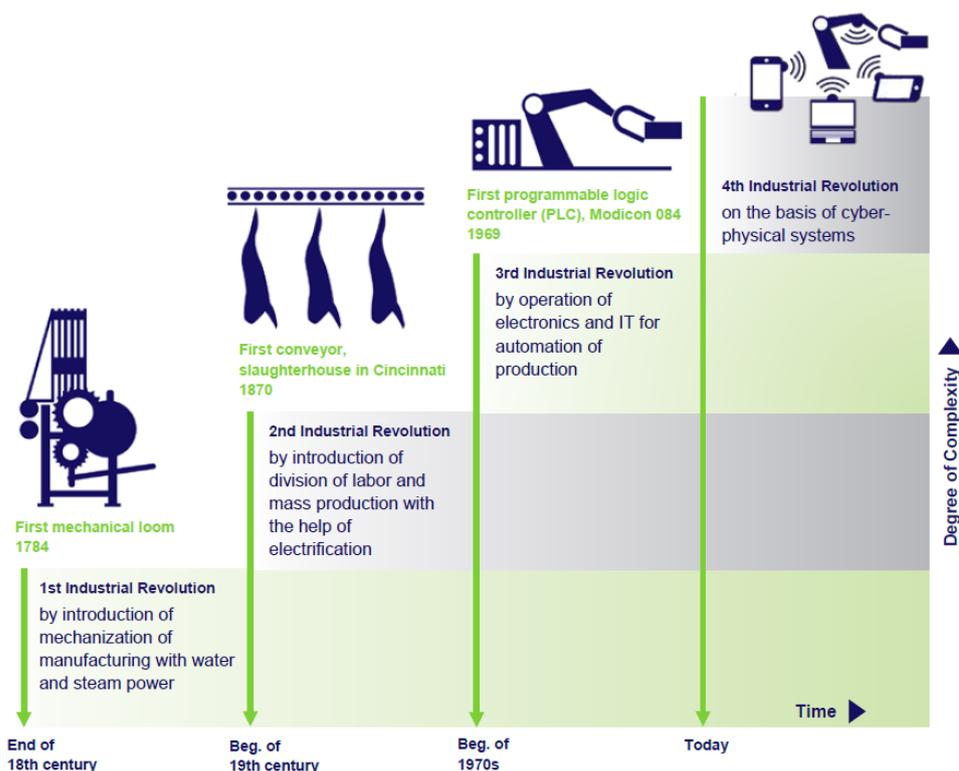


Figure 1. The four industrial revolutions (graphic by [Kagermann et al., 2013], translated from German)

The Second Industrial Revolution

During the Second Industrial Revolution, technological advances in steel and iron production, as well as the invention of the light bulb and the division of labor, changed manufacturing once again. The further development of transportation technologies enabled better transportation of goods and the start of mass consumption. Combined with electricity as an energy source, mass production started in the late 19th century [Chandler, 1990]. Henry Ford's assembly line revolutionized how products were produced by decreasing the time it took to manufacture an item. Trains shortened travel times between cities and the development of cars and bicycles improved the mobility within cities. The development of the scientific management of manufacturing processes [Taylor, 1911] and the invention of the production line [Lisciandra, 2008], respectively known as Taylorism and Fordism, had profound influences on manufacturing. These developments influenced society and changed the work environment in manufacturing. It was the start for mass production and for example simplification of tasks for workers in an assembly line as well as documentation of assembling processes to provide interdisciplinary knowledge.

The Third Industrial Revolution

The next major step in the evolution of manufacturing was the development of microcontrollers leading to digitalization of the factory. The Third Industrial Revolution began in the middle of the 20th century and introduced automation and microelectronic technology into manufacturing. The development of transistors, industrial robots [Nof, 1999], digitalization, and computer technology led to automation of manufacturing and thus transformed the necessary qualifications and skills of the factory worker, e.g. demanding the knowledge to work with a computer. The introduction of Six Sigma and Lean Management, which focuses on optimization by means of removing production inefficiencies, influenced the development of work in assembly lines and factories [Chiarini, 2012]. Another important influence is computer-integrated manufacturing (CIM) which is the integration of computers into the planning and production processes with the objective to control the entire production process. All these drivers and technologies have led to our current situation in the factories within the USA and Germany.

The Current Situation and Fourth Industrial Revolution

In current manufacturing, automation technology is ubiquitous and workers are required to be much more flexible. Many workers utilize computerized-numerical-control (CNC) machining centers and other means of industrial automation on the shop floor or they assemble products with tools. Automated production like welding or painting by robots is separated from the human workers because robots are not able to sense the presence of workers and the current setup of automated manufacturing cells is too dangerous for workers. A great amount of effort is put into the production planning of manufacturing processes to achieve the optimal profitability in the short and long term [Pfeiffer et al, 1994, p. 53].

At the present day, manufacturing is on the brink of the Fourth Industrial Revolution. The digitalization of manufacturing is optimizing the shop floor with integrated technologies and communication technologies. With these new integrated systems, it is possible for the factory of the future to be adaptive with respect to the production of individualized products in small batch sizes. Automation will be increasingly important but a completely autonomous factory is inadvisable from a control and economic standpoint. With the growing numbers of sensors utilized on the shop floor, there will be a lot more data drawn from manufacturing processes, allowing for further analysis and optimization. This will make assistance systems and services more important in the future. Analyzed data will then help factory workers make smarter decisions and optimize processes.

One of the revolutionary changes in the Fourth Industrial Revolution will be the introduction of cyber-physical systems (CPS). CPS are networks of interacting elements, including sensors, machine tools, assembly systems, and parts, all connected through digital communications networks. The data collected by these networks will be represented virtually and the processes controlled remotely. CPS are working as a system by definition and forming a part of what is often referred to as the Internet of Things (IoT). The IoT can be understood as a data and information cloud that is conceptually quite similar to that of CPS in that it consists of embedded systems communicating through a network. However, the IoT has a broader scope since its components can be functioning independently and not only include CPS [Federal Ministry of Education and Research, 2013]. According to Zuehlke, the internet of things "will likely be a non-deterministic and open network in which auto-organized intelligent entities (e.g. Web services) and virtual objects will be interoperable and able to act independently pursuing their own objectives (or

shared ones) depending on the context, circumstances or environment” [Zuehlke, 2010].

With the introduction of CPS, every part of the factory will be represented as an object with properties in the network. Machines will communicate with each other and decentralized control systems will be able to optimize the production sequence. The manufacturing process will consist of small standardized and combinable steps where each product knows its path along the production sequence. There may be different products in the same manufacturing line and the machines and workers have to be flexible in case of changes in the production process. The working environment will shift to control or monitoring centers where the skilled laborer will have control of the manufacturing process. Some workers may be able to work from home most days with mobile devices since the networked systems could run over encrypted lines to an authorized mobile devices. Through this shift, the work of product developers and production workers will come closer to each other and potentially merge. Figure 2 shows this development in a factory of Industry 4.0 and introduces the principles of vertical and horizontal integration. The merging of planning and development with the production is called vertical integration. With the networked production, interconnections and data and information exchange among departments and companies will increase, thus making integration and communication more important which is called horizontal integration [Federal Ministry of Education and Research, 2013] [Ganschlar, 2013].

Virtual reality and speech recognition, as well as the use of augmented reality, will change how work is performed [Bienzeisler et al, 2014]. For example, information or graphical instruction displayed over

smart-glasses allows the user to see work instructions while performing critical activities. Another example may be the direct collaboration of robots and humans working hand-in-hand together without barriers.

Organizations and Programs to Shape Future Manufacturing

The factors that led to the first three industrial revolutions and are currently stimulating the development of the Fourth Industrial Revolution included various public and private initiatives. These initiatives may have been as simple as government contracts for military weapons, such as those that led to the development of the interchangeable part [Alder, 1997] and some of the first machine tools [Ford, 2005]. However, more recently, initiatives focus not only on the products being manufactured but also consider the impact of the development of new manufacturing technology on the economy and those who work in the manufacturing sector. An excellent example of how modern manufacturing research and development is carried out can be seen in the Fraunhofer Society.

Founded in 1949, the Fraunhofer Society is an applied manufacturing research institute with 67 institutes mainly spread throughout Germany, but also with sites in Europe and around the world. The bulk of the funding for the institute is provided by industry partners that pay the institute to research manufacturing technologies directly related to their business. In exchange, the institute provides their expertise in advanced manufacturing research. The institute also provides industry with a pipeline of young engineers and technicians who have been trained to use new manufacturing technologies. The development of



Figure 2. Vertical and horizontal integration under Industry 4.0 (graphic by [VDI-Wissensforum], translated from German)

these qualifications and skills in manufacturing workers is a critical component of the Fraunhofer Model and serves as the primary example for many new manufacturing initiatives that are being developed [Fraunhofer Gesellschaft, 2015].

A good example of a United States' initiative that is being developed based on the Fraunhofer Model is the National Network for Manufacturing Innovation (NNMI). Introduced in 2011, the NNMI serves to create an effective manufacturing research infrastructure for United States industry and academia to solve industry-relevant problems [Advanced Manufacturing National Program Office, 2013]. Future funding for the network may be provided by the Revitalize American Manufacturing Innovation Act of 2014. Further, the Manufacturing Universities Act of 2014 authorizes the National Institute of Standards and Technology (NIST) to designate up to 25 institutions as U.S. manufacturing universities that are to be awarded funds over a four-year period. Founded by AT&T, Cisco, GE, Intel and IBM in March 2014, the Industrial Internet Consortium is also an important driver of innovation in the economy. This initiative from the USA is for example involved in the idea of the IoT and has the objective to facilitate open forums about current technologies and innovations, influences global standards, and is concerned with the security of industrial networks [Industrial Internet Consortium].

Another important initiative focused on manufacturing innovation is Industry 4.0; a German government initiative meant to act as a catalyst for the fourth industrial revolution. The initiative predicts that the revolution will be characterized by the implementation of cyber-physical systems (CPS) in factories.

Smart factories using CPS will be able to track all manufacturing processes and parts through digital networks, allowing for more effective horizontal integration of supply chains. It has also been predicted that smart factories in the fourth industrial revolution will be highly adaptable and reconfigurable, allowing for vertical integration of products with customized features [Kagermann et al., 2013].

While Industry 4.0 is focused primarily on German industry, the European Union has its own research and innovation initiative, Horizon 2020, with almost €80 billion of funding available from 2014 to 2020. The initiative targets a broad spectrum of research including €13.5 billion focused on industrial technology development, €3 billion to provide small and medium enterprises (SMEs) with leadership in enabling industrial technologies, and €2.8 billion to fill the “innovation gap” between the academic and commercial development of technology [Publications office of the European Union, 2014]. Part of Horizon 2020 is the initiative “Added Value Manufacturing” that is planned for 2016. It is similar to the German Industry 4.0 initiative and it is planned to start a knowledge and innovation center concerned with this topic in the entire European Union [EIT, 2015] [Chrysolouris, 2012].

The initiatives described above should provide increased improvements in manufacturing technology and generally improving the economies of both the US and Germany. However, the greatest contribution the initiatives will make is providing skilled laborers with the skills and qualifications needed in the factory of the future.

3 The Future Manufacturing Worker - Qualifications and Skills

The vision for the factory of the future has been developed. Evidently, the work performed by the skilled labor on the shop floor in a factory of the future will differ significantly from the situation in today's factories. Consequently, the qualifications and skills of the skilled labor, which are required to fulfil the tasks occurring in a factory of the future, will differ as well [Northcott et al., 1990], [Spath, 2006], [Strategy & formerly PricewaterhouseCoopers, 2014], [Hirsch-Kreinsen, 2014], [Roland Berger Strategy Consultants, 2014], [Bauernhansl et al., 2014].

The Approach

The approach taken to make recommendations for qualifications and skills for the factory worker of the future is portrayed in Figure 3 and described in the following.

The approach we followed to derive the recommended qualifications and skills consists of the analysis of three tiers. As indicated in the pyramid, the 3rd tier constitutes the basis for the 2nd tier which in turn constitutes the basis for the 1st tier.

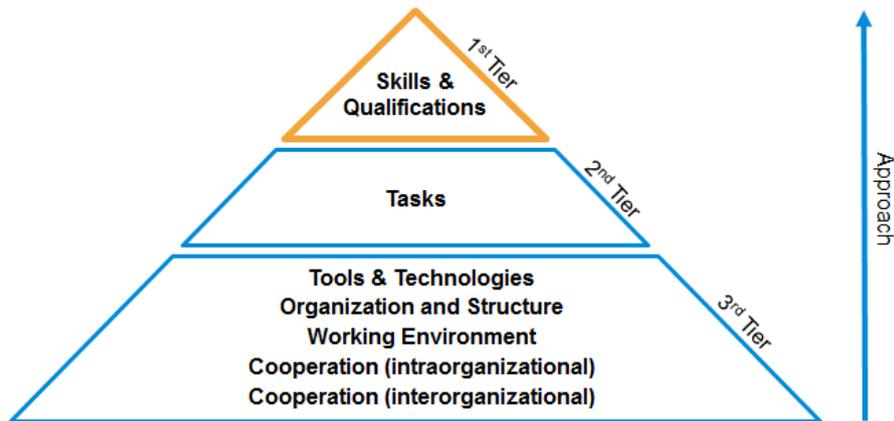


Figure 3. Approach to derive qualifications and skills for the factory worker of the future

Commencing from the 3rd tier, we expect the following four¹ factors to have a large influence on the human factor and fundamentally change in a factory of the future:

- Tools and Technologies
- Organization and Structure
- Working Environment
- Intraorganizational and Interorganizational Cooperation.

Thereby, *Tools and Technologies* refer to all kinds of tools and technologies that the skilled labor uses and by which the skilled labor is affected. For example, workers in a contemporary factory work with tools such as automated screwdrivers and technologies such as CNC machines. *Organization and Structure* includes the organizational setting in which the skilled labor performs their work. Examples for this area are the number of different hierarchical levels in the workplace or the way the teams are set up. *Working Environment* considers the physical environment that directly affects the production workers because they perform their work within the working environment. Considered are, for example, production factors that appear in the working environment such as machines, robots, or other things that shape the working environment. *Intraorganizational and Interorganizational Cooperation* summarizes all kinds of cooperation and communication of the skilled labor within the factory and with external partners.

The above areas are defined as 3rd tier factors and they determine *tasks* of skilled labor. The type of

¹ Henceforth, the factors intraorganizational and interorganizational cooperation are pooled into one factor.

tasks these workers perform in a factory, both currently and in the factory of the future, are among others a function of the manifestation of the mentioned areas. For example, the existing tools and technologies, which are available to assist skilled labor, and the responsibility or job description of the workers in the factory, determine the degree to which skilled labor performs manual labor or activities such as planning and supervising. The tasks, which are derived from the 3rd tier factors, are defined as the 2nd tier factor.

Finally, the qualifications and skills of skilled labor can be derived from the existing tasks and create the 1st tier factor. More specifically, the qualifications and skills which are required for the skilled labor to perform work efficiently are determined by the tasks occurring at work. Similar to the manufacturing environment today, there needs to be a fit between qualifications and skills of workers and the tasks they have.

The Manifestation of Third Tier and Second Tier Factors in a Factory of the Future

Following the outlined approach, the different factors are characterized with respect to the vision we have of the situation in a factory of the future.² Thereby, it is assumed that the described future situation applies for

² Please note that the following is a description of the vision for the factory of the future we have developed based on our education and experience. We generally refer to other authors where we have identified an exact overlap of their and our vision. However, since the purpose of this paper was to develop a vision based on the perspective of ten early career engineers from the USA and Germany, we have largely tried to use our own words.

the USA and Germany because both countries work towards a fully integrated smart factory that efficiently utilizes information through cyber-physical systems and a qualified workforce in order to improve manufacturing [Mattauch, 2014]. As a result, the difference between both countries is not considered when determining the recommended skillset of the manufacturing worker of the future. In the following, the vision we have for the manifestation of the third tier factors in the future is described briefly. Thereby, ‘future’ always refers to a situation, in which the idea of advanced manufacturing or Industry 4.0 has become reality and is not specified to a certain date.

Tools and Technologies

We expect the tools and technologies skilled labor uses and is in contact with to be notably different in comparison to today’s situation. In general, automation and intelligent tools, machines, and technologies will advance and the need for the skilled labor to perform manual tasks will decrease. All kinds of smart devices such as pads, wearables, or phones will provide the worker with the exact information they need in real time or in a certain situation to perform their task efficiently. Integrated into the digital world of the factory, i.e. into the internet of things, the workers are able to control and monitor production processes through the analysis of data and information supported with these devices. Intelligent assistance systems with optimized human machine interfaces will further make it possible for the worker to make qualified decisions in a shorter time despite the very complex situation on the shop floor. Also new kinds of machines will enter the workspace.

Collaborative robotics will be sensitive and intelligent enough to share a work station with humans. These robots support the worker, for example in situations that are critical with respect to ergonomics. The robots of the future are easily programmed and can be integrated into production smoothly. Furthermore, different technologies, such as Automatic Identification (Auto-ID), will relieve the workers from very simple jobs enabling them to focus on more qualified activities. In general, machines, robots, materials, and other devices will advance and become so-called cyber-physical systems through the integration with cutting-edge information technologies that will integrate them into the new eco system.

This advancement on the technological level will also affect the human in a way that the intelligent tools and technologies will become more autonomous and automated. Nevertheless, the supervision and efficient application of machines by humans will become more important than ever before. The trends towards the situation in a factory of the future can already be identified by some tools and technologies that are

used today, such as smart phones or other connected devices.

Organization and Structure

Historically, technologies can only perform at high efficiency if organization and structure of a company provide the right environment for them [Duimering et al., 1993], [Cardoso et al., 2012], [Bauernhansl et al., 2014]. That is, there must be a fit between the used technologies and the existing organization and structure. Consequently, a significant change in the used technologies should and will proceed jointly with a significant change in organization and structure. Governed by vertical and horizontal integration and enabled by cyber-physical systems, as well as the internet of things, the organization of a factory of the future will be more flexible, changeable, decentralized, and not as deterministic as the organizations of today [Henke, 2014].

The fact that different production areas will move closer together will have an especially profound effect on skilled labor. Workers, capable of working with the information and data flow, will not necessarily be bound to a certain production area anymore. Production jobs will be allocated based on the qualifications and skills of workers but the new abilities the workers experience through their smart devices will improve the possibilities of job rotation and job enrichment immensely. We expect all jobs of skilled labor to be enriched in a way that they will have larger responsibility and more decision-making power. The workers on the shop floor will be greatly organized in different short and long term teams to focus on solving the problems that occur. The companies or organizations will provide an ecosystem in which problem solving is done in collaboration with all participating parties on the shop floor and without much influence of a higher hierarchy [Bauernhansl et al., 2014].

Once the skilled labor receives more decision-making power and influence, the organization and structure of companies will become more flat. That will not only have an effect on the skilled labor but also on engineers and managers of the lower hierarchical levels as they need to cede parts of their decision-making power.

Working Environment

In the recent past, the world of industrial production was perceived from the outside as being a dark and dirty place with no windows where raw physical work is carried out by a horde of men. Even though this perception is a bit exaggerated and has mostly changed for the better (i.e. factories are cleaner and

more organized and women are entering the manufacturing workforce), the perception of the working environment of the future will again be distinctly different. The future working environment will be an open and creative space, similar to what technology companies, such as Apple and Google, have today. Young engineers perceive it to be very clean, bright, and a nice place to be and work for both men and women. In addition to this perception, the working environment will further affect the skilled labor.

Through the rather generalized qualifications and the information integration, the skilled labor will enjoy a larger flexibility with respect to their shifts or working day. The shift allocations will be more transparent, enabling better planning for the workers and hence improving the work-life-balance. Entirely new shift models are also likely to emerge enabled through technologies that make it obsolete to stand at one specific production station for the course of the entire shift. These technologies will also fuel the trends toward home office working. One could also imagine a scenario in which the labor, which is responsible for a production area, gathers and supervises the production processes from a shared control room on the basis of advanced team work. In addition, the working environment on the shop floor will look very different from today's situation.

Modern assistant systems will provide the workers with the ability for quick decision making despite the increased complexity of their job contents. Machines, robots, and devices can be manipulated through new human-machine-interfaces that have perfected intuitivity with respect to the operation, programming, and supervision. The work will be improved with respect to ergonomics. In particular, processes in the workplace with poor ergonomics or those that do not engage workers in a creative or thoughtful manner are likely to become automated in order to favor the production workers.

Intraorganizational and Interorganizational Cooperation

In the factory of the future, intraorganizational and interorganizational cooperation and communication will increase significantly. The formerly mentioned expectations about more teamwork, fueled by the vertical and horizontal integration and other organizational changes, translate directly into more cooperation and communication both along the vertical and horizontal organization and value chain. Networking and interconnectedness are focal components of the Industry 4.0. Workers will collaborate and communicate without borders as they will be utilizing smart devices which connect them in real-time to their co-workers and workplace tools as needed. This online

communication will exist in parallel to the existing offline communication of today improving the collaboration and transparency in a factory a great deal.

The internet provides the possibilities to meet globally in virtual rooms at almost any time and to reach out for required information as needed. Different kinds of workshops, seminars, and training sessions can be executed within the cyberspace. That not only makes them cheaper but will also benefit from higher attendance. All kinds of information and data will be ubiquitous and at the fingertips of the workers leading to a whole new level of knowledge management. For example a problem that is reported at a production station anywhere in the world could be put online within a matter of minutes and is instantly available for other sites of the production network that could run into the same problem. Highly relevant problems could also be pushed on the respective devices right away minimizing the time between identifying and solving an error.

Learning curves within production networks will increase strongly due to the described interconnectedness. Furthermore, humans in a factory of the future will not only communicate with other humans but also with the other new participants within the internet of things, i.e. all kinds of cyber-physical systems, such as robots, machines, or the actual product. How such a shift of communication patterns could look like within a smart factory of automotive production is indicated in Figure 4. It can be observed that the rather unidirectional communication between a worker, a machine, and the direct co-workers advances into a situation of multidirectional communication amongst humans and machines along the entire process chain. The mentioned new devices and technologies thereby facilitate an integrated and interconnected communication and collaboration [Wehinger, 2014].

The possibilities discussed can thereby apply for both the intraorganizational and interorganizational cooperation. How the inter-organizational communication will further develop in particular can already be seen today in the area of digital and remote maintenance, where service providers are able to access robotics systems in a manufacturing plant from outside the factory to perform service updates or react to errors right away. The IT security will have to advance and be error free to enable the broad diffusion of such cooperation. However, due to the great effect on the overall efficiency within a factory, the inter-organizational cooperation will increase a great deal. Additionally, the amount of different external parties involved in collaborations will increase. For example, collaborations with research institutes, universities, and parties that are not classical suppliers will increase due to the interdisciplinary character of digital production or Industry 4.0.

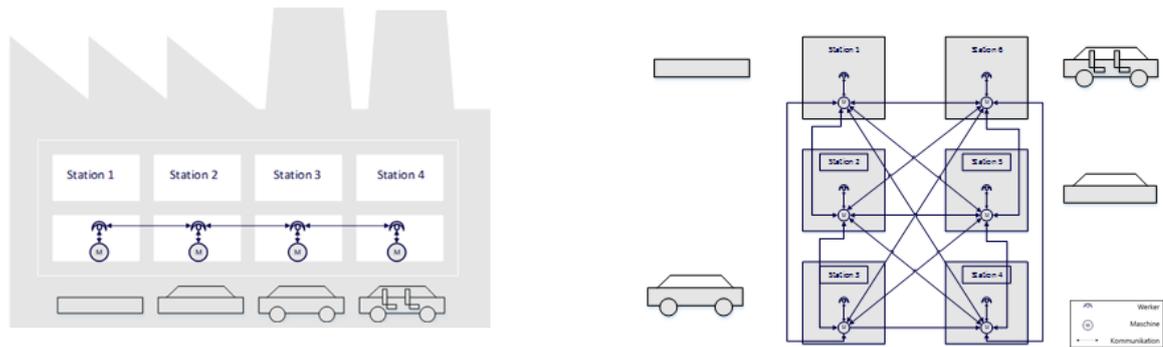


Figure 4. Exemplary communication patterns in factories of today (a) and the future (b). [Wehinger, 2014]

Tasks in a factory of the future

Typical tasks in a factory of the future can be derived from the aforementioned factors of the third tier. In general, the skilled labor will enjoy a greater task variety than today. Monotonous and ergonomic challenging tasks will be decreased to a minimum if not erased entirely for the human workforce because modern machines and robots will release them from unhealthy and very monotonous tasks. As a consequence, the worker will be free to perform more qualified work. Their new tasks will entail a great deal of data and information processing as the production processes in a factory of the future are not merely organized by the material flow anymore but governed by the information flow.

Information and data will be the basic elements the skilled laborer works with, using all kinds of new devices and assistance systems. The tasks they are able to and have to perform with these devices will also increase in quantity. Teamwork will be central, not only throughout the vertical and horizontal levels within the organization and along the value chain, but also at the actual working place with new kinds of assistant systems. These assistant systems will support work significantly, but most of the final decisions will remain with the skilled labor which is why the new technology will only assist and not replace the human. However, this assistance will be crucial as the workers will have to make decision and perform tasks with a greater scope than they do today.

The interaction among these systems, machines, and robots in the factory will be eased as well. The artificial intelligence of the machines will enable a collaboration and communication between humans and machines with similar means as in communication among humans. The human will be able to interact with the intelligent partners, not only by pressing or touching, but also by voice or gesture. The tasks that are performed will involve less manual work and more tasks of control and supervision of processes.

Within the scope of vertical integration, the planning aspects will move partly into the responsibility of the workers of the shop floor and will support the industrial engineers with tasks like process improvements and waste reduction.

Recommended Qualifications and Skills for the Worker in a Factory of the Future

Based on the derived tasks, which arise from the manifestation of the 3rd tier factors in a factory of the future, future qualifications and skills of the skilled labour can be recommended. More specifically, there are certain qualifications and skills that will become more important in the future and that should complement the existing set of qualifications and skills of the skilled labour of today. Due to the shift towards the mentioned informatization of industrial production during the course of the fourth industrial revolution, it is likely that the hereafter listed qualifications and skills will also gain in importance towards the current qualifications and skills of the skilled labour. However, the core qualifications and skills that are mediated in a classical technical apprenticeship of today, such as the basic knowledge about materials or metal processing, will remain in the core of the education of the skilled labor.

From the analysis of the derived tasks, a list of different qualifications and skills, which will be important for the skilled labour in a factory of the future, could be generated. The qualifications and skills of that list differ in their importance. In order to prioritize and add more structure to the list of qualifications and skills, the prioritization technique “MuShCo” was applied [Maxwell, 2010]. This method serves to allocate elements to the three priorities “Must”, “Should”, and “Could” of which “Must” has the highest and “Could” the lowest priority. Applied to the problem at hand, the factors could be further specified into “Must...”, “Should...”, and “Could be included in the

skillset of the production worker of the future”. Furthermore, the identified skilled were segmented into two categories: technical and personal qualifications and skills (Q&S). In order to address the issue of subjectivity in such a prioritization, the priorities of all ten team members and different experts from the ASME and VDI are considered to create the final prioritization. The result of this method is shown in Table 1.

Based on these results, it can be seen that different technical and personal qualifications and skills become important:

On the technical side, especially skills and qualifications with respect to IT, information and data processing and analytics, an organizational and process understanding, and the ability to work and interact with modern interfaces are prospectively of high value for the skilled labor. Due to the omnipresence of information and data and the integration of different business processes, the workers need to gain knowledge management abilities and an interdisciplinary understanding of their organization, its processes

and used technologies. Additionally, a certain sensitivity for IT security and data protection will be mandatory. Technical skills that will definitely be useful, yet not necessarily required are for example computer programming or coding abilities or similar very deep technical knowledge. The factory worker of the future will be more a generalist than a specialist.

It can further be recommended that the qualifications and skills of the skilled labor on a personal level develop into the direction of the personal education of managers and engineers of today. That is, soft skills such as social and communication skills as well as team working and self-management abilities, which are all skills managers and engineers are currently trained at, become very important for the skilled labor as well. Currently, the typical factory worker does not enjoy training in those areas because the job content does usually not necessitate the application of these skills. However, in a factory of the future, there will not only be significantly more teamwork on the shopfloor level but also more teamwork and communication in daily business. Due to greater responsibilities and influence of the workers, there evolves

Table 1. Qualifications and skills of workers in a factory of the future *

		Must...	Should...	Could...
		<i>...be included in the skillset of the skilled labor of the future.</i>		
Technical Q&S	IT knowledge and abilities		Knowledge Management	Computer programming/coding abilities
	Data and information processing and analytics		Interdisciplinary / generic knowledge about technologies and organizations	Specialized knowledge about technologies
	Statistical knowledge		Specialized knowledge of manufacturing activities and processes	Awareness for ergonomics
	Organizational and processual understanding		Awareness for IT security and data protection	Understanding of legal affairs
	Ability to interact with modern interfaces (human-machine / human-robot)			
Personal Q&S	Self- and time management		Trust in new technologies	
	Adaptability and ability to change		Mindset for continuous improvement and lifelong learning	
	Team working abilities			
	Social skills			
	Communication skills			

* The order of listing within the three categories does not indicate a prioritization among the factors of the respective category. The table shows the most important qualifications and skills as identified throughout the project. The list is not intended to be exhaustive.

a need for self-management and other general management skills. A trust into the new technologies and assistance systems will be inevitable because without the use of these technologies, the workers will not be capable of performing on a high level. A general

mindset for continuous improvement and lifelong learning will be precious as the dynamics of changes in industrial production will only become more intense.

4 Workforce Development - Current Situation in Germany and the USA

From the analysis of future qualifications and skills described in Chapter 3, two main outcomes can be derived:

- In order to be successful in the manufacturing sector, a skilled workforce is needed today and will be needed in the future.
- The set of needed qualifications and skills will fundamentally change.

These facts pose challenges to workforce development in different dimensions. On the one hand, measures are needed to develop and train the existing workforce; on the other hand, the whole educational system has to be adapted to meet both the current and future challenges. In order to recommend ways for the USA and Germany to mediate the identified qualifications and skills to prepare factory workers for the jobs of the future, a basic understanding of the educational systems in the USA and Germany needs to be gained. Hence, it follows a description of the educational systems of both countries. This description is based on Figure 5, which gives an overview of both educational systems covering the entire workers' lifecycle from primary school to continuous vocational training.

The educational system of both countries can be divided into three main blocks: 1) primary and secondary school, 2) higher education including transition from school to work, and 3) continuous vocational training. Both systems start with primary school and different forms of high schools, both in the USA and Germany.

The transition from high school to work is addressed in different forms in the USA and Germany. While students leave secondary education to go to college, university, or other technical or specialized schools in both countries, Germany has established the dual system of vocational training as an alternative career path. At the top of both systems stands continuous vocational training that has nowadays gained enormously in importance [Autorengruppe Bildungsber-

ichterstattung, 2014], [Institute of Education Sciences, 2015]. In the context of workforce development for the production worker of the future, each of the three phases plays a decisive role and is therefore analyzed in detail in the following sections. Thereby, the focus lies on different programs and initiatives of each phase that exist today in the USA and Germany and that serve to prepare the education for the needs of the future.

Early Education

Primary and secondary school provide the fundamental education that is deepened within specialized programs in higher education. In the manufacturing sector, especially technical skills are of high importance. These technical skills are often referred to as so called STEM³-skills, which stands for basic knowledge in science, technology, engineering, and mathematics. In order to train young people with the necessary STEM-skills, schools in the USA and in Germany have launched various initiatives that contribute to the established curricula.

For example, North Rhine-Westphalia in Germany promotes STEM education in schools within special programs since 2001. It created the quality label "MINT Schule". Here STEM days and camps are organized for students from various secondary schools [MINT, 2014a]. Another program is "MINT-EC", which provides a wide range of events and funding for students as well as training and professional exchanges for teachers and school administrators. "MINT-EC" is a national excellence network of 42 schools with upper secondary education and a distinct profile in STEM subjects [MINT, 2014b]. Also in the

³ STEM is comparable to the Germany "MINT", which stands for Mathematics, Informatics, Natural Science and Technology.

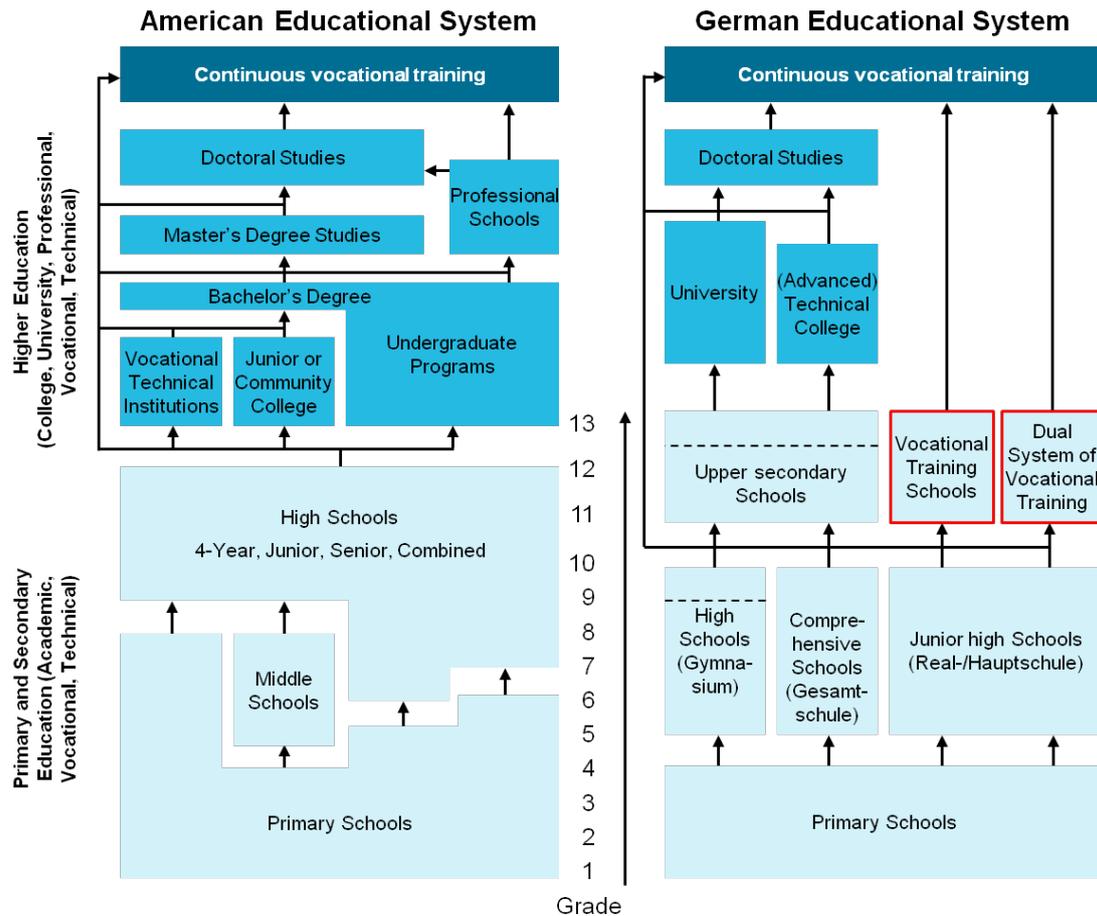


Figure 5. Chronological flow charts of American and German educational systems [Institute of Education Science, 2015], [Autorengruppe Bildungsberichterstattung, 2014]

USA, various programs with a STEM focus in education have been created. For example, the math and science partnership program is designed to improve the knowledge content of teachers and the performance of students in the areas of mathematics and science. Partnerships between high-need school districts and STEM faculties in institutions of higher education are the core of the program [U.S. Department of Education, 2014]. Another initiative is OC STEM, which is a growing network of students, teachers, parents, and businesses with the mission to improve the quality and outcome of STEM teaching and learning in Orange County, California [OC STEM-Initiative, 2015].

STEM-initiatives are a good example on how to adjust the curricula at school to certain needs arising within the job market. The early introduction of students to STEM-topics gives students an understanding of technical principles and exposes young people to future career opportunities [Drage, 2009]. However, the boundaries between various STEM disciplines are blurred noticeably. For example, computer science does not work without mathematics and technical innovations arise from scientific knowledge and so on. Additionally, information and communication

technology change our communication and our decision-making. New areas of expertise arise rapidly leading to the need of readjusting the curricula at school in even shorter cycles. Therefore, flexibility within the primary and secondary education is needed as well as new concepts making sure that the requirements from the job market are integrated.

Transition from School to Work

While early exposure to STEM fundamentals and to future career opportunities is important for generating interest, the transition from school to technical development is another critical element of delivery of students from school to the workforce. This transition is addressed in different forms for the USA and Germany.

Both the USA and Germany view the skilled workforce as a critical element to growing and reinforcing the industrial manufacturing base. The future of advanced manufacturing environments, aided by development initiatives, will rely on training and education systems already in place to deliver the workforce with the necessary technical skills [Mital et al., 1999].

Germany relies primarily on the dual system, this system delivers vocational education and training (VET) through split time at a vocational school and a cooperative company. The dual system is available to all students who have completed secondary school. Attainment of students for this system is high, with 64% of the students who leave general education in Germany enrolling in the dual system [Wang, 2011]. While the German system favors the parallel-path dual system for training of the skilled workforce, the USA relies on a number of different independent workforce development programs. The dual system was implemented in the USA by some programs such as the German embassy's Skills Initiative, but its adoption has been limited and the country's primary system continues to be a mix of technical schools, community colleges, and on-the-job training [Gitter et al., 1997].

Germany and the USA have different labor challenges to overcome in securing the workforce necessary to advance the manufacturing industry. Germany already has a national system in place for VET and the US is making progress in VET in combination with STEM programs for students in middle school and high school with programs like Project Lead the Way (PLTW). While implementation of a dual system in the US has only been moderately successful, nationally recognized or sponsored VET programs are gaining support [Drage, 2009]. The function of each country's development systems is to prepare students with the necessary fundamentals and skills to perform and excel in their future job functions. The future challenge for both the United States and Germany will be to not only meet the demand of skilled labor for manufacturing, but also to additionally diversify the training and development offered to cater to an advanced industrial environment [U.S. 21st Century Workforce Commission, 2000].

Continuous Vocational Training

Employees entering the workforce will ideally have all the skills necessary to perform their job, but over the lifetime of a working life, the necessary skills and knowledge change quickly. Continued training for employees to develop new skills and keep technical skills at a high level is a major need in the manufac-

turing industry [Pennathur et al., 2003]. The advantage of formal training for manufacturing Industries is clearly evident which is presented in a study performed over three years and 180 manufacturing firms. The US Department of Labor reported formal training increased productivity of production workers by 20% while decreasing scrap rates by 7% [Mital et al., 1999].

The need for continuous learning or training can be addressed using similar methods as the initial vocational education and training (VET) through training centers and dual programs. The need for employees to stay productive throughout their career and not be absent from work for extended period of time away from work leads most employers to perform in-house training that is only moderately effective. This in-house training is attempted to be accomplished through online learning modules, mentoring systems, and onsite seminars. The challenge of these methods is ensuring the quality of the delivery systems is kept at premium level and the absorption of the information is at a high level [Mital et al., 1999].

The proper method of effectively providing continuous education throughout a worker life is still up for debate. Providing continuous education is especially challenging for SME because the lack of large pools of resources hinder efforts to create in-house organized development structures [Mital et al., 1999]. The challenge of maintaining skill applicability to the modern work environment will continue to be a problem for both SME and Industries as a whole. SME must utilize all available avenues to cost effectively train their workforce. These include existing on-site training, local trade centers, and community colleges or cooperative training with industry partners [Robertson, 2003].

Standardization of training during the working life cycle could extend the education life cycle displayed in the former section into a working life cycle. The development cycle of an effective skilled worker would then not only include the traditional fundamental education blocks and VET included in Figure 5, but would also extend into the working career of the skilled employee. This extended life-cycle would fully encompass the lifelong learning paths of a technical laborer as a model for maintaining a qualified technical workforce.

5 Recommendations - Preparing for Future Manufacturing

Based on the findings of Chapter 3 and Chapter 4, a number of different measures are recommended to qualify the workforce for the requirements in a factory of the future. More specifically, the hereafter recommended measures address the required qualifications and skills for skilled labor and consider the three identified phases of the educational path: beginning with school and ending with continuous vocational training. Table 2 introduces the measures of qualifications and evaluates them towards the technical and personal qualifications and skills identified in Chapter 3. Thereby, the evaluation ranges from “well-

sued” to “not-suited”. A “well-suited” measure is capable of delivering a certain qualification or skill very effectively, a “suited” measure does so in a moderately effective way, and a “not-suited” measure is not useful to deliver a respective qualification or skill. The recommendations given below address the parties capable of influencing the education or qualification of the skilled labor, i.e. companies, governments, and associations such as the VDI and ASME. An elaboration of a selection of the recommendations is described below.

Table 2. Evaluation of measures for the qualification of the skilled labor

		Technical Q&S														Personal Q&S						Eval.	
		IT knowledge and abilities	Data and information processing and analytics	Statistical knowledge	Organizational and processual understanding	Ability to interact with modern interfaces	Knowledge Management	Interdisciplinary / generic understanding	Specialized knowledge	Awareness for IT security and data protection	Computer programming/coding abilities	Specialized knowledge about technologies	Awareness for ergonomics	Understanding of legal affairs	Self- and time management	Adaptability and ability to change	Team working abilities	Social skills	Communication skills	Trust in new technologies	Mindset for improvement	++ = Very Effective (>70% of max. effectiveness) + = Effective (>50% of max. effectiveness)	
Early education	Mandatory school subjects	●	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	+
	School Internships	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	+
	Summer school initiatives	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	+
	Open day tours	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Transition from School to Work	2Yr. 'light' manufacturing degree	●	●	●	●	●	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	++
	Engineering mentoring program	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	Workshops	●	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	++
	Internships	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	+
	Professional Development Courses	●	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	++
	MOOC	●	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	Open day tours	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	University/industry collaboration	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	++
Continuous Vocational Training	MOOC	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	+
	Workshops	●	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	++
	Open day tours	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	Industry/university collaboration	●	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	+
	Department presentations	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	Professional Development Courses	●	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	++

● well-suited ○ suited - not suited

In addition to evaluating the recommended measures towards each identified qualification or skill, the overall effectiveness of the measure is calculated. In this case, a measure is defined as being 100 percent effective, if it is evaluated “well-suited” towards all qualifications and skills listed in the table. Additionally, the measures are allocated to the categories “very effective” (above 70 percent of maximum effectiveness) and “effective” (above 50, but below 70 percent of maximum effectiveness). The following description focuses on the very effective and moderately effective measures. The description of other measures, which are especially useful for very specific qualifications and skills, is deliberately kept concise.⁴

Phase 1 – Early Education

Due to the great influence of the early phases of the educational path, manufacturing exposure must occur early in the educational system to substantiate the manufacturing movement from the current state of manufacturing to the future vision. It is clear that attention must be drawn to manufacturing early in education to promote and sustain a continuous talent pipeline.

Mandatory school subjects

At the core of the first phase “Early Education”, we recommend an adjustment of mandatory school subjects. In order to prepare a workforce that fulfills the activities within a factory of the future with ease, subjects related to STEM become more and more important. Since not only the manufacturing sector but also the majority of all other sectors will be influenced by the pace of technological development and new possibilities enabled through information technologies, the entire society would benefit if these subjects were put on a more obligatory basis at schools. While courses of computer science or simple word processing are mostly just electives today, these courses should be integrated into the compulsory curriculum at schools early on. Along with that, the awareness of the pupils about the importance of these information technology-based subjects for their work-

ing life and careers should deliberately and purposefully be increased at schools.⁵

Additionally, **school internships**, which are already offered at the collegiate level to some extent, should become more common and adjusted towards the identified qualifications and skills. These measures expose collegiate students to jobs in their selected field of study where they can gain insights on job particulars and gain valuable personal skills. Internships are the first step to helping a student’s transition from the learning phase to a job phase on the career path. With proven success, for both the student and the company, it is recommended that manufacturing companies and schools develop internship programs collaboratively. For the students it is an opportunity to inherit qualifications and skills related to current technologies and an exposure to manufacturing.

Summer schools and field trips

Summer schools and similar non-classroom events are other avenues to breach the talent pipeline early. The concept of summer schools already exists within different phases of the educational path. For the early education phase, we recommend to extend the current offering by adding programs that are aimed at young students and that have topics of computer sciences in the focus. A short one-month program could be offered to students in which they can get in touch with novel technologies and learn about computer sciences. These programs could be enhanced by field trips to manufacturing plants or other science facilities. The concept of field trips or open day tours at production plants, whether or not combined with a summer school program, is an additional approach to expose younger audiences to what manufacturing can offer in terms of employment. Simultaneously, it provides the manufacturing plant and company with a public relations opportunity. By highlighting key stages of manufacturing or demonstrating unique manufacturing processes, potential employees can see what shop personnel do for work and the type of systems they work on. Hence, it is recommended for manufacturing companies to invest in public shop times or open day tours. In general, the summer school programs or non-classroom events should be designed with a fun-factor for students to make the early learning process as exciting as possible.

⁴ In the chosen evaluation methodology a measure is more valuable if it addresses a broad array of qualifications and skills rather than if it addresses only a specific qualification or skill.

⁵ Also compare [U.S. 21st Century Workforce Commission, 2000] for US-based strategies towards building the future workforce.

All in all and referring back to Table 2, it can be seen that the measures of mandatory school subjects, school co-operative opportunities (internships), and summer schools have the highest effectiveness within the first phase of education. It can be observed that especially mandatory school subjects and co-operative opportunities are strong in delivering technical qualifications and skills. That is because these kinds of qualifications and skills can be passed on well through theoretical classes and experience which are areas the two measures address. Whereas the mandatory school subjects perform poor on the level of personal qualifications and skills, the internships and open day tours are evaluated as mostly suited for these skills. Reasons are that the pupils will have to use and therefore train their personal skills when they are engaged with other people and technologies either over a longer (internships) or shorter (summer school programs) stretch of time.

Phase 2 - Transition from School to Work

Professional Development Courses

In the following section, the focus lies on the very effective recommendations, listed and evaluated in Table 4.1. Regarding the derivation of our recommendations, Professional Development Courses are specific and topic-related courses that prepare (under-)graduates for their upcoming working life. For instance, a course about robotics aims to give insights into the state of play of the robotic market and transfers extensive comprehension and programming skills for participants of this course in order to navigate robots. This recommendation is evaluated as very effective (see Table 4.1) and addresses primarily technical qualification and skills.

Workshops

Workshops are evaluated as a very effective recommendation in which technical qualifications and skills are reinforced and developed. The main reason this recommendation is very influential is that its content can be modified to the interest and goal of the creator or the principle of the workshop. This fact also contributes to the great evaluation of workshops, since they can be used to train both, technical and personal qualifications and skills. Whereas workshops can deal with almost any technical topic, they are also well-suited and commonly used to deliver soft skills, for example about self-management, teamwork, and effective business communications.

University/Industry collaboration

They will gain in importance, thus it is recommended to enforce the collaboration and adjust them better to the required qualifications and skills. Not only set amounts of internships reserved by an enterprise specifically for university students, but also and particularly a stronger involvement in research projects between the two parties, are examples that belong to this recommendation. Students will get in contact with companies on behalf of their universities and learn about and develop their research projects. For example, many companies in the United States hire entry level positions and collaborate with local universities to continue to develop these new workers. This recommendation is considered to be very effective, reinforcing mainly technical qualification and skills such as organizational, process and interdisciplinary understanding and specialized knowledge about technologies. Nonetheless, this recommendation is very well-suited for personal skills like trust in new technology and mindset for improvement due to the students' involvement in entrepreneurial work.

Two year “light” manufacturing degree

The two year “light” manufacturing degree emerges to be not only a very effective but also a very characteristic recommendation, especially for the second phase. Typically, a collegiate degree is achieved with four years of schooling with broad and in-depth educational requirements. A four-year degree, however, will not be particularly suited for the worker on the shop floor in the factory of the future, but neither will be a high school education. By deriving skills required for the worker in the factory of the future, a two-year technical associate's degree is suggested. Similar to mono-skilled focused technical studies, such as learning to weld, this educational program would focus on the identified qualifications and skills presented in this study. Such a degree would be considered a tradesman or technical degree for individuals who want to work with additive or advanced manufacturing. The primary focus will not be gaining a specific skill, such as welding in this example, but exposing students to run automated machines, writing computer code, and developing technical skills needed to run the factory of the future. This technology-based education will not only focus on specialized manufacturing but also on data processing and statistics, which are essential to future factory workers. Thus, this recommendation concentrates rather on technical skills and qualifications than personal qualifications and skills.

Internships

Students spend a certain amount of time in companies learning about their processes and fulfilling specific duties, are estimated to be an effective measure for the qualification of the skilled labour. Internships are mainly well-suited for organizational and process, as well as interdisciplinary understanding and personal or team working abilities. The more the students or people in general get in touch with new technologies and organizational measures at companies, the better they are prepared for the challenges of working life.

The three upcoming recommendations are not evaluated as very effective or effective in *Table 4.1*. Engineering mentoring programs are programs in which Engineering students are guided by a full-experienced mentor. This mentor gives his or her mentee advice whenever needed and exposes him to relevant engineering topics. Massive Open Online Courses (MOOC) are especially advisable for advanced training where no interaction with other parties is needed. Therefore, rather informative facts than technical qualification and skills can be acquired. Participating in Open Day Tours, students will have a chance to get an insight into a company's manufacturing setting. Among others, this measure is therefore well-suited for the mindset of improvement and trust in new technologies.

Phase 3 - Continuous Vocational Training

The subsequent phase takes a further step towards the educational path and deals with company initiatives for on-the-job training. Companies can maintain profitability and remain on the fore-front of manufacturing by tapping into the talent supply chain, developing employees and generating the needed skilled talent through Continuous Vocational Training [Accenture, Manufacturing Institute 2014]. Whether entering the workforce after attaining a high school or higher level degree, it is essential to continue on the path of life-long learning. It is clear that current manufacturing companies can maintain productivity by having a talented and skilled workforce; however, even after hiring talented employees, it is essential to invest and to continue to develop these employees. When Accenture and the Manufacturing Institute surveyed more than 300 US manufacturing companies in 2013 and 2014, it was found that 80% of these companies invest in employees with training programs spending on average \$1,000 annually per employee [Accenture, Manufacturing Institute 2014].

Workshops

This underlines the fact that workshops are considered to be a very effective measure. The difference to the workshops applied in the second phase lies in the addressing of not only technical but also personal skills. Moreover, the content of the workshops becomes more specific and goal-oriented. For example, relevant topics of workshops could be an introduction to the various principles of Industry 4.0 (technical) or a topic such as time and self-management supported by advanced manufacturing technologies (personal).

Professional Development Courses

They are a very effective measure reinforcing technical and personal skills. In this phase, courses have a more specific content and can be tailored to exact needs. Hence, after completing Professional Development Courses, a certificate can be attained, comparable to the acquirable Six Sigma certification.

Industry/University collaboration

It is at first glance repetitive, however, this time it is rather focused on the industry perspective. Now companies should stay in contact with universities and to collaborate with them in order to engage them in a relevant field of research, evolving from an existing problem. It is beneficial for companies to collaborate with universities because they have the capacities, facilities, and knowledge to process and run research projects. Universities can address politicians and government when education needs to go into a certain direction triggered by the industry. This measure is evaluated as effective and addresses mainly technical qualification and skills such as IT knowledge and abilities, the ability to interact with modern interfaces, and personal skills as mentioned in the second phase. Despite the above-mentioned investment, as shown in the survey of Accenture and the Manufacturing Institute [Accenture, Manufacturing Institute 2014], these companies have reported only modest satisfaction. What has been found effective is digital learning experiences where learning is self-paced and available during work and non-work hours.

Massive Open Online Courses (MOOC)

They are also considered to be a measure in this phase, with the difference that it is evaluated "effective". In the Continuous Vocational Training phase more specific topics can be narrowed and company processes and their interdepartmental interfaces can be transmitted. Thus, this measure is well-suited for rather specialized knowledge as well as organizational and process understanding.

The measures not listed in Table 4.2 and therefore not being very effective or effective are Open Day Tours and Department Presentations. The latter can be done regularly and strengthens the organizational and interdisciplinary understanding as well as personal skills like trust for technologies and the mindset for improvement.

Recommendations towards ASME and VDI

In addition to these recommendations, we have recommendations specifically for the professional societies of ASME and VDI. Both societies already show their engagement with respect to the preparation of the workforce for future challenges (among others, fostering of this project) and we do not intend to be exhaustive with our recommendations towards them. However, the following are ideas that evolved within the course of the project and that are intended to initiate further activities in both societies to support the establishment of a future workforce for the manufacturing sector.

First, it is recommended to professional societies, such as ASME and VDI, to become deeply involved with the elementary education systems by offering a scholastic membership for the high school or pre-high school levels. Memberships could have a reduced subscription or be offered for free until the workforce or collegiate level is reached. On the other side, membership fees could be subsidized by schools as well. This offering will engage young students to join professional societies and enjoy the benefits these societies can offer. This will give students access to events, data, and broad engineering communication. This recommendation addresses, not only trust and understanding of new technology, but also supports the idea of lifelong learning from an early age.

Especially for the younger members and the student members, the ASME and VDI should act as a connector between schools, university, and the industry. Both societies can make great use of their broad business network and initiate various gatherings such as company presentations at schools or field trips to companies and manufacturing plants for students. The more the younger generation gets in touch with manufacturing and new technologies, the more they are likely to develop an interest towards these areas. The first step of the qualification initiatives must always be to increase the awareness of the novel topics of

advanced manufacturing and Industry 4.0 which can be well-enabled through these measures. At a further stage, the societies can use their close ties to the industry to support pupils or students to find internships, which in turn, would have the above-mentioned benefits towards the qualification of the future workforce.

The ASME and VDI should also focus on connecting the industry players with research institutes and universities to fuel the establishment of research projects. The interdisciplinary topics of advanced manufacturing and Industry 4.0 are well-suited to be explored through these kinds of projects as they require novel and more scientific approaches than the ones the industry is used to. In Germany, research projects with consortiums consisting of companies and research institutes have gained popularity, among others due to the trending topic of Industry 4.0. We recommend the mentioned societies to further encourage these kind of engagements as they are also a very useful measure to realize a knowledge spillover from the researchers of the institutes to the workers of companies and vice versa.

The ASME and VDI should tailor selected offerings and programs towards the topics of advanced manufacturing and Industry 4.0 not only for the young members, but also for students and members with a finished education. Some of the recommendations mentioned above, such as summer schools or the lite manufacturing degree could be established or supported by the engineering societies of ASME and VDI as they are likely to possess the majority of required resources. Especially workshops, which are evaluated as being very effective for the qualification of the future workforce, can be set-up by the societies. The ASME and VDI should offer workshops similar to the ones various consultancies are currently offering. As a differentiation towards the consulting workshops, though, the engineering societies could open them for more people than the consultancies do. A workshop concept of them should be tailored to the working group that is in discussion within this study: the skilled labor. The list of required qualifications and skills were provided in *Table 2.1* could be of use to construct the workshop concepts and contents.

Lastly, the societies are in a position in which they can and should focus on developing standards for different areas of modern manufacturing such as human-machine-interfaces or the human-robot-collaboration.

6 Summary

The manufacturing industry continues to be a central driver of growth for economies worldwide and the impact of manufacturing on economies and societies over time has always been significant. The magnitude of the change to human kind caused by manufacturing can be well-perceived by the effects of the first, second, and third industrial revolution. Enabled through continuously advancing technologies, people now live longer, healthier, more productive, and more fulfilling lives than they did before the first industrial revolution took place around the end of the 18th century. Currently, advanced economies such as the USA and Germany are on the brink of the fourth industrial revolution. This revolution is governed by the interplay of advanced manufacturing and information technologies that enable yet another significant gain in productivity and overall improvement of manufacturing through the merging of cyber and physical worlds. In an effort to strengthen and increase their respective economies and manufacturing sectors, the USA and Germany have funded initiatives to spur on this revolution. The USA refers to their program as the Advanced Manufacturing Program (AMP) and Germany refers to theirs as Industry 4.0. For both initiatives as well as for the entire fourth industrial revolution to be a success, there is one thing that must be considered in all activities and that must even occupy a first-priority: **The People**.

Similar to the previous three industrial revolutions, the fourth industrial revolution with its advanced manufacturing and information technologies provokes a change process for the people working in direct and indirect areas of manufacturing. The people will have to be able to adapt to the new technologies and the organizational changes they imply. A central part of this adoption process will be preparation of qualification principles for workers that make them ready for the new area of modern manufacturing.⁶

Against this background, the project team identified and set the following major objectives for this paper:

- Introduce the matter of the fourth industrial revolution.

⁶ This study is deliberately focused on the effects on the workers of the shop floor (in this study referred to as skilled labor) since the authors determined this group is likely to experience the largest change process through the introduction of the fourth industrial revolution.

- Describe the effects of this revolution on the skilled labor.
- Derive qualifications and skills that will become more important for the workforce.
- Recommend ways and measures to qualify the workforce for the future against the background of the educational systems of the USA and Germany.

Thereby, the order of these objectives also reflects the approach that is taken in this study. After a motivation and introduction to the matter of the fourth industrial revolution, a focus lies on the description of the effects this revolution will have on the workforce. The skillset of the workforce in a factory of the future is identified through a three-tier approach. A description of the educational systems of the USA and Germany lays the foundation for various recommendations for qualification measures to prepare the workforce for the future and the future workforce. These recommendations address parties able to influence the qualification of workers such as companies, politics, and societies like the ASME and VDI.

The mentioned skillset, which is recommended for the workforce of the future, consists of various technical and personal skills. Technical skills especially include knowledge, abilities, and skills in the different areas of IT and personal skills should include soft skills such as time and self-management. Qualification measures should address different phases of the educational path of which we identified the phases, “early education”, “transition from school to work”, and “continuous vocational training” as anchor points of qualification measures. A range of qualification measures, such as mandatory school subjects, professional development courses, and workshops tailored to the identified qualifications and skills for the future workforce are recommended.

Due to the novelty of the entire topic of advanced manufacturing and Industry 4.0 there is still a large need for research in various areas. However, in close relation to the content of this study, we recommend to carry out an analysis about the likely changes of jobs in engineering and other indirect areas of manufacturing. The approach and recommendations of this study can constitute a guideline for such studies.

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ASME Project Responsibility

ASME helps the global engineering community develop solutions to real world challenges. Founded in 1880 as the American Society of Mechanical Engineers, ASME is a not-for-profit professional organization that enables collaboration, knowledge sharing and skill development across all engineering disciplines, while promoting the vital role of the engineer in society. ASME codes and standards, publications, conferences, continuing education and professional development programs provide a foundation for advancing technical knowledge and a safer world. For more information visit www.asme.org.

VDI Project Responsibility

Engineers need a strong association that supports, promotes and represents them in their work. This task is performed by the VDI Association of German Engineers. For over 150 years it has steadfastly backed engineers. More than 12,000 honorary experts process the latest findings every year to promote our technology location. That's convincing: with about 154,000 members, the VDI is the largest engineering association in Germany. As the third largest standards organization we are also partner for the German business community and scientific organizations. The project is funded by Reinhard Frank-Stiftung.

VDI The Association of German Engineers
Claudia Rasche
Germany, Düsseldorf
Phone: +49 211 6214 455
rasche@vdi.de
www.vdi.de

ASME American Society of Mechanical
Engineers
Michael Tinkleman, Ph.D.
USA, Washington
Phone +1 202 785 7394
tinklemanm@asme.org
www.asme.org